Gamma Spectroscopy of Neutron-Rich Nuclei with the CLARA/PRISMA Setup

E.Farnea

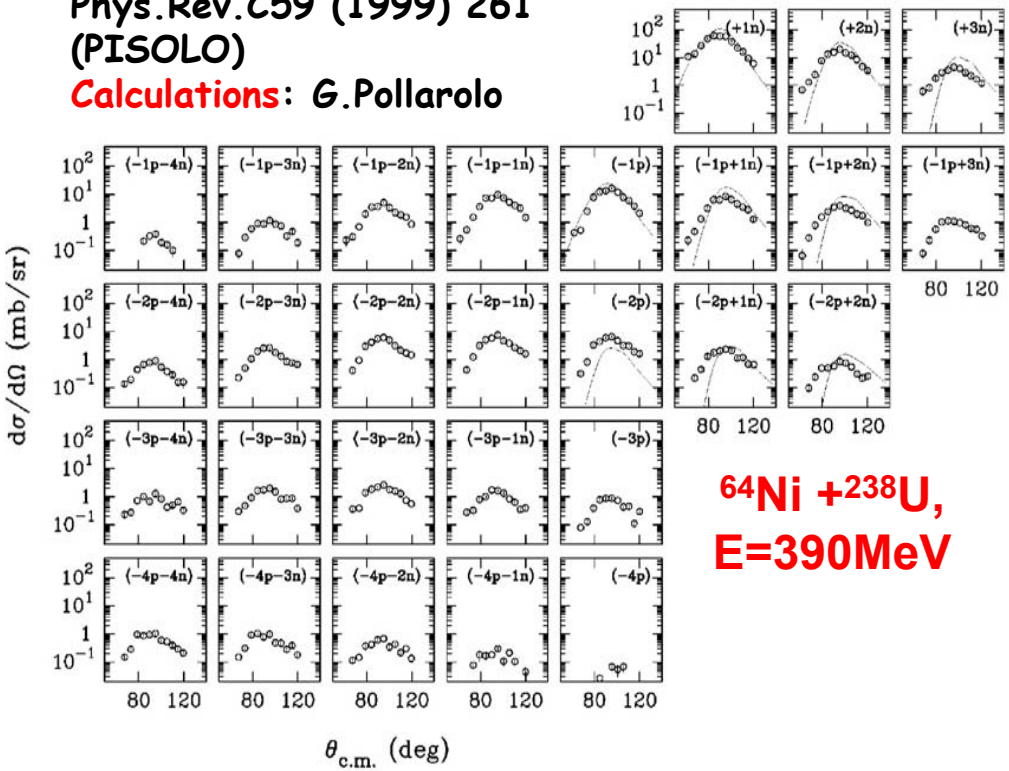
INFN Sezione di Padova

on behalf of the CLARA/PRISMA Collaboration

1) Gamma Spectroscopy with Multinucleon Transfer and Deep-Inelastic Reactions
2) PRISMA and CLARA
3) Results from the experimental campaign

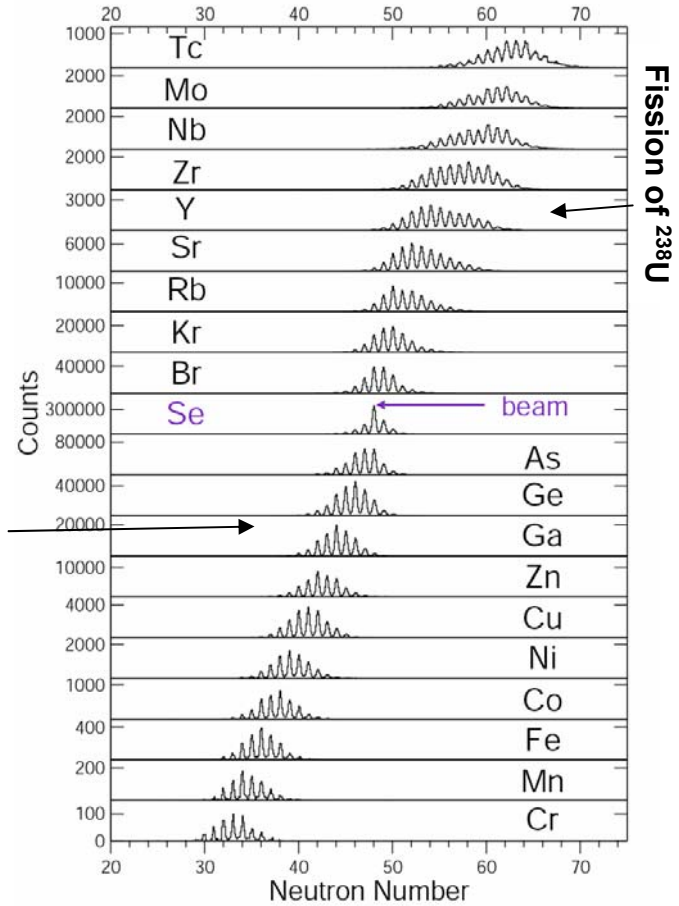
Grazing reactions as a tool to study n-rich nuclei

Exp. Data: L.Corradi et al., Phys.Rev.C59 (1999) 261 (PISOLO)
Calculations: G.Pollarolo



^{64}Ni +^{238}U, E=390MeV

^{82}Se + ^{238}U, E=505 MeV



Multinucleon transfer and deep inelastic reactions between stable nuclei at low and intermediate energy provide a convenient way to populate many nuclei far from stability which would be impossible to reach with fusion-evaporation reactions.

PRISMA Exp. Data
Inelastic channels only
(γs detected with CLARA)

Grazing reactions as a tool to study n-rich nuclei

Exp. Data: L.Corradi et al., Phys.Rev.C59 (1999) 261 (PISOLO)
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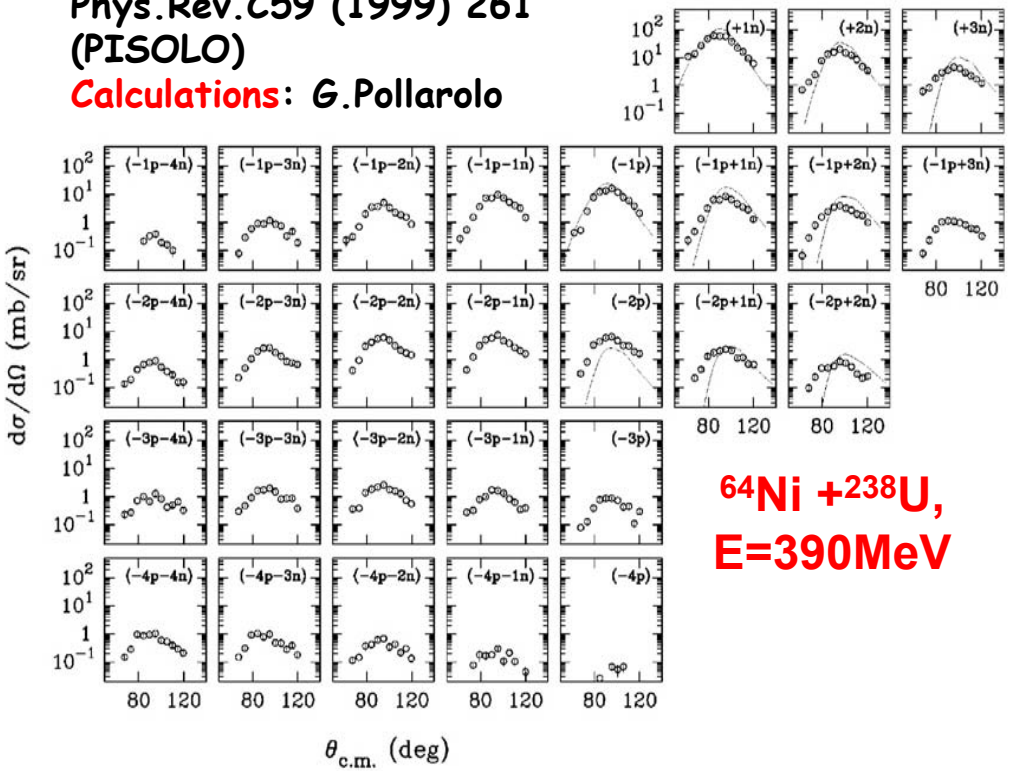

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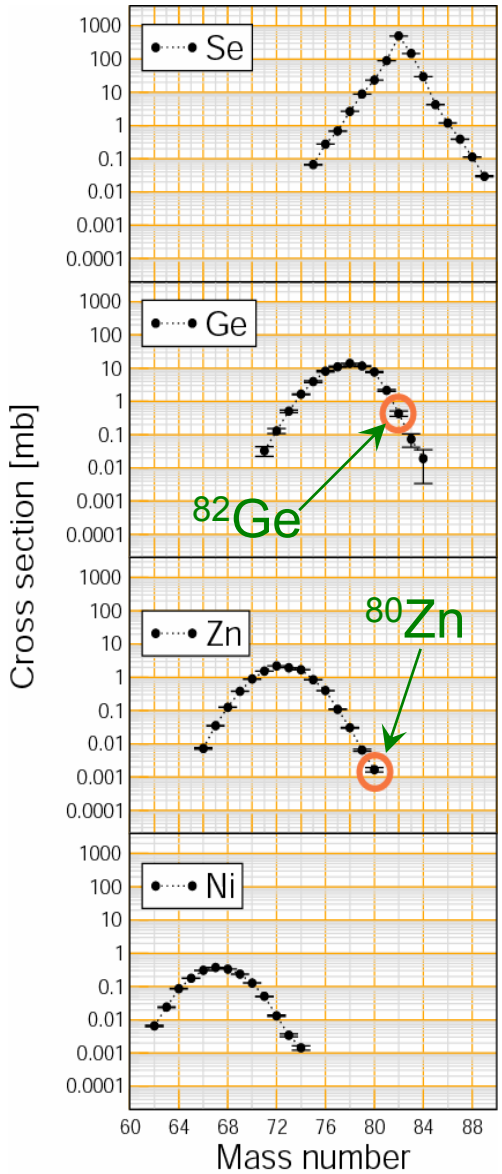
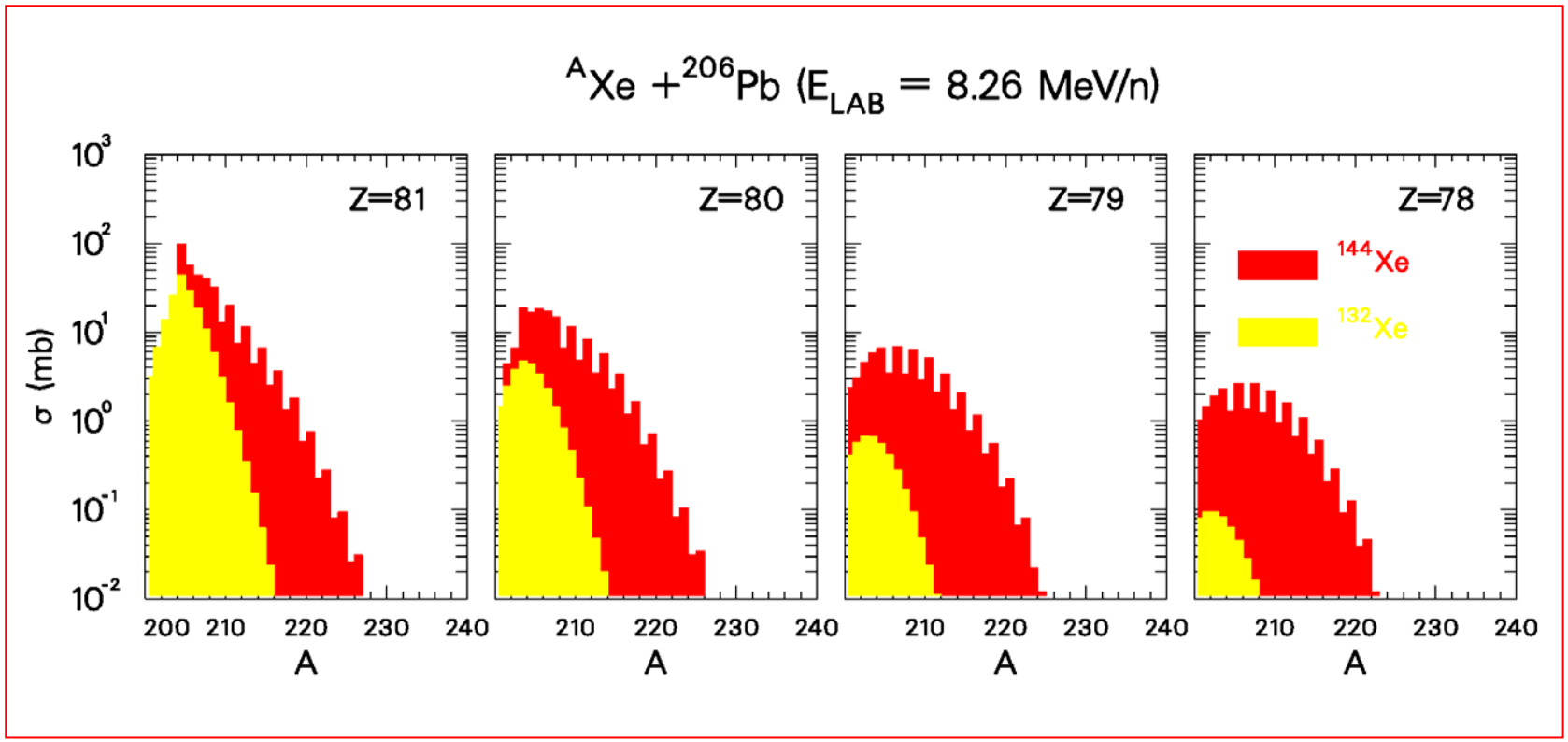


Multinucleon transfer and deep inelastic reactions between stable nuclei at low and intermediate energy provide a convenient way to populate many nuclei far from stability which would be impossible to reach with fusion-evaporation reactions.

In many cases, the production cross sections are not negligible.

Neutron rich RIBs: a tool for very neutron rich nuclei



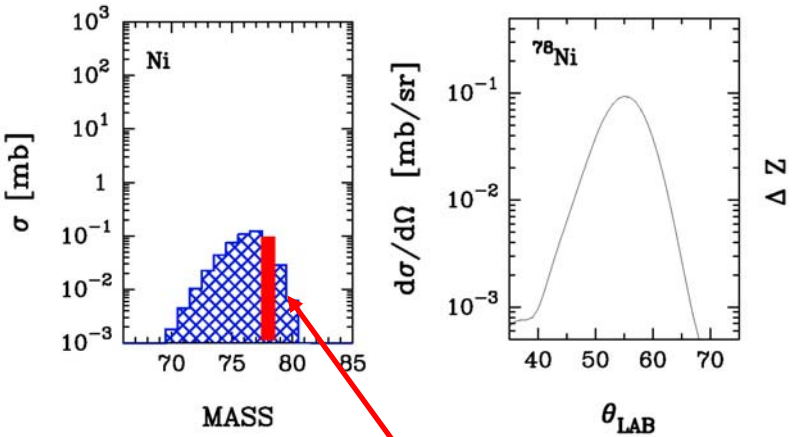
Coupled channel calculations (Grazing) by G. Pollarolo

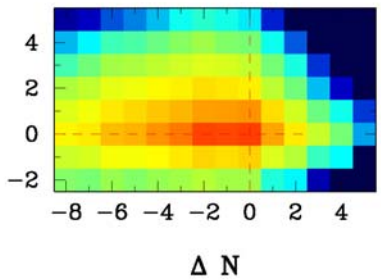
We expect that multinucleon transfer and deep inelastic reaction will be an essential tool also when radioactive beams are available, due to the enhancement of the cross sections and to the shift in the population distribution.

Transfer with RIBs at Coulomb barrier Energies

Calculations by G.Pollarolo

$^{80}Zn + ^{238}U$ (460 MeV)





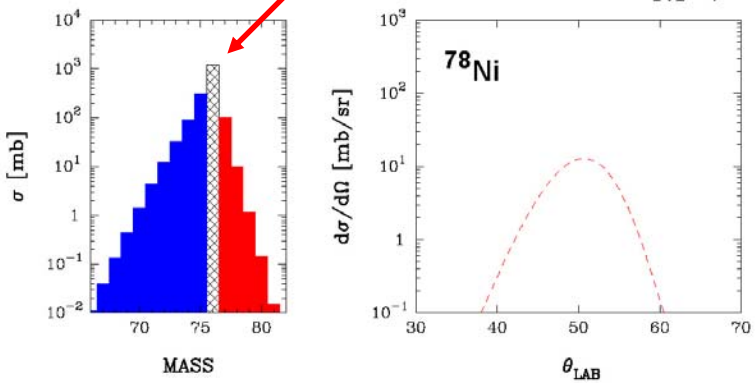
dσ/dΩ=100μb

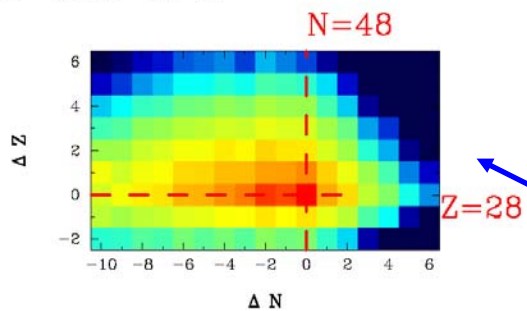
^{80}Zn beam

^{78}Ni

Careful selection of the beam will be needed to study specific channels

$^{76}Ni + ^{238}U$ (450 MeV)





dσ/dΩ=10mb

^{76}Ni beam

γ-Ray Spectroscopy with Grazing reactions

Possible approaches:

Thick target experiment

→ Channel selection is an issue
(cross-coincidences with the reaction partner)

→ Doppler correction is not an issue
(but cannot resolve short-lived states)

*See e.g. Broda et al, PRL **74** (1995) 865*

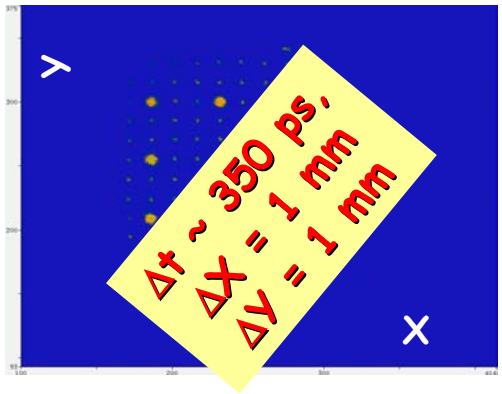
Thin target experiment

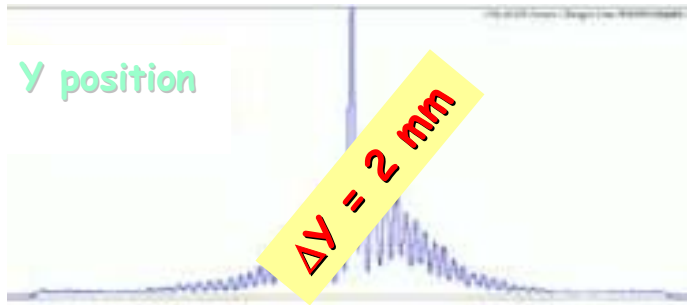
→ Channel selection is an issue

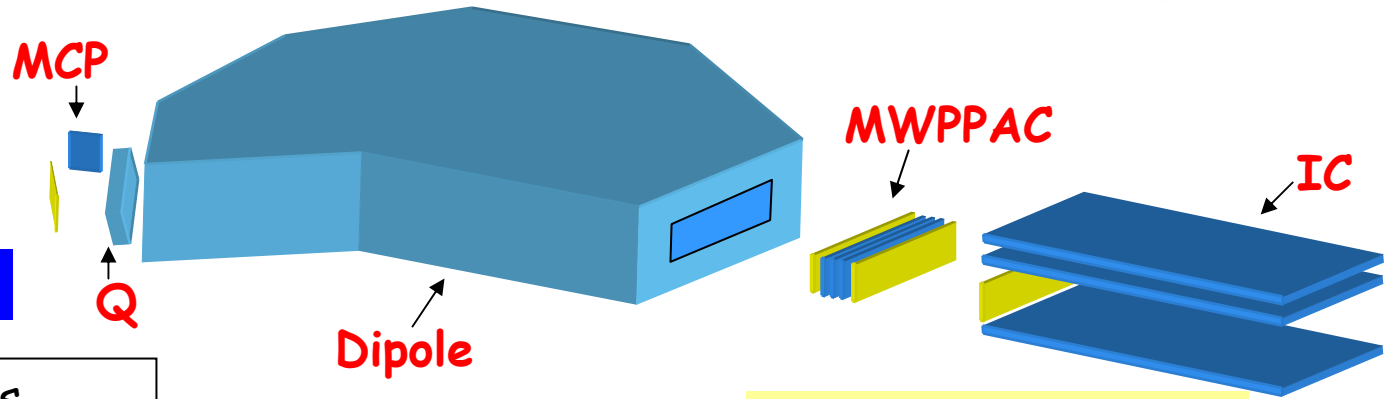
→ Doppler correction is an issue

→ CLARA/PRISMA approach

The PRISMA Magnetic Spectrometer







See talk by P.Mason

Z, A, β of the recoils through combination of:

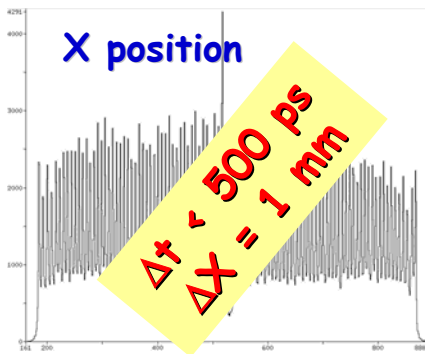
→ Energy

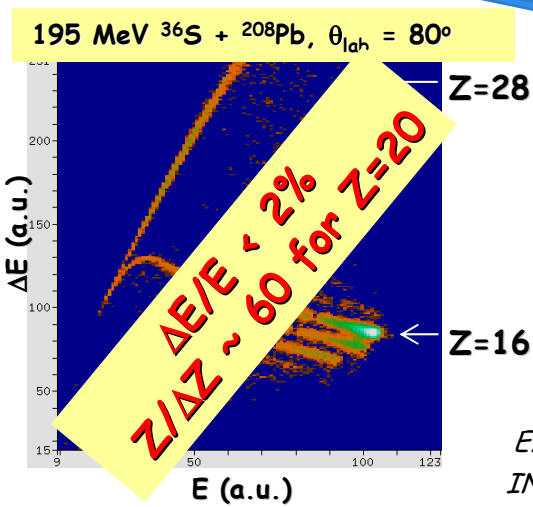
→ TOF

→ ΔE–E

→ Focal plane position

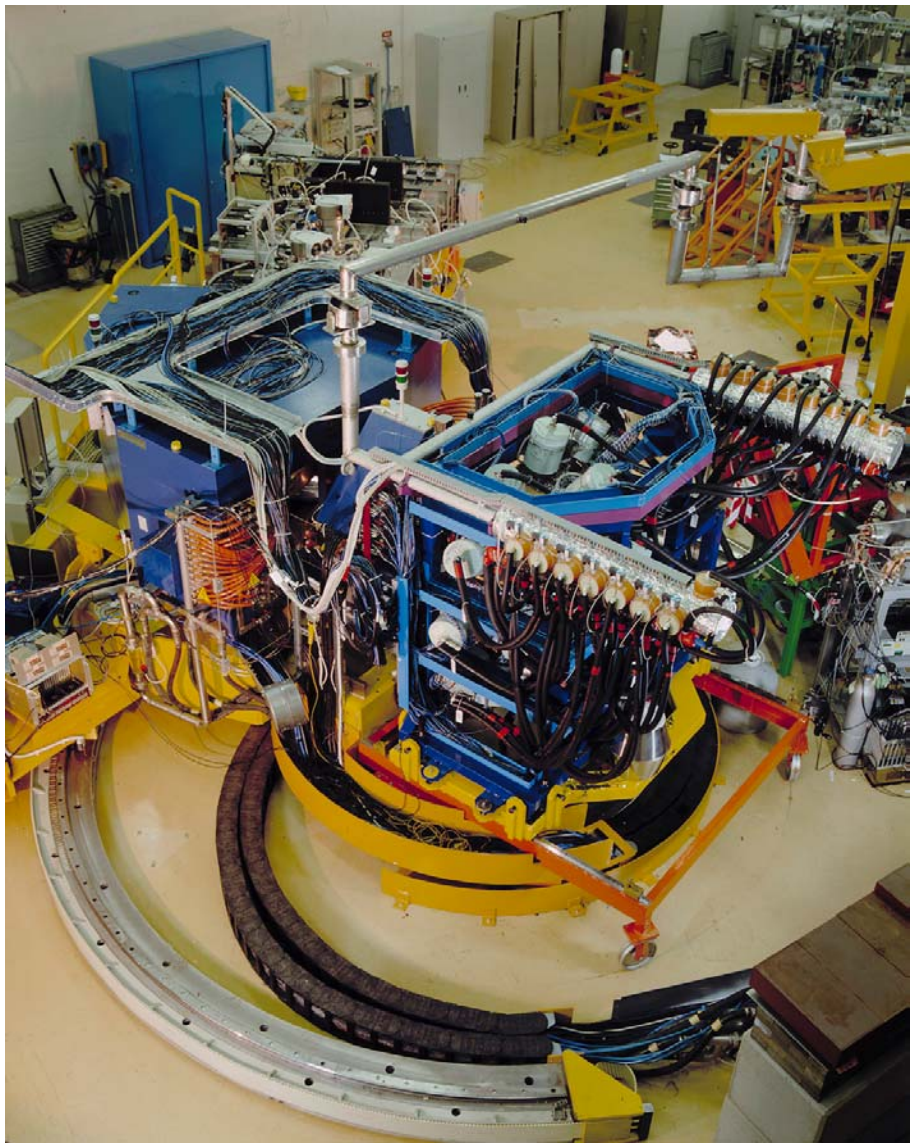
Direction from the start detector

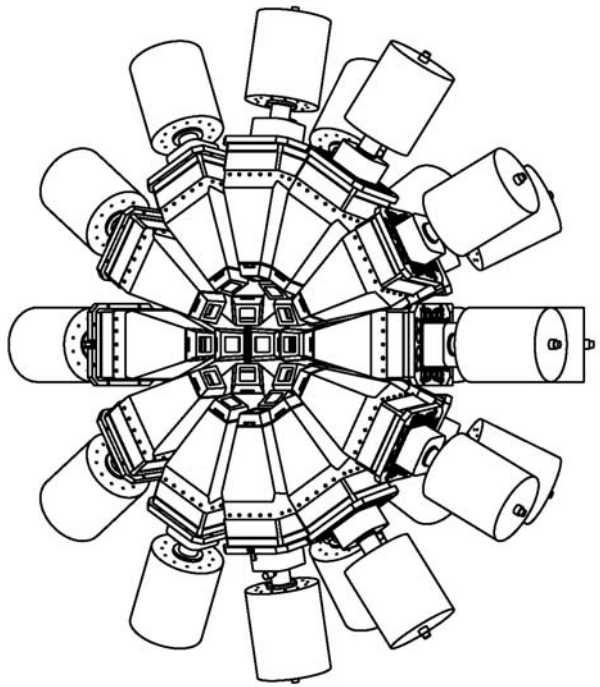




E. Fioretto
INFN - LNL

CLARA: Clover Detector array





Up to 25 Euroball Clover detectors (from the EU GammaPool)

For $E\gamma$= 1.3MeV:

Efficiency ~ 3 %

Peak/Total ~ 45 %

FWHM < 10 keV (at v/c = 10 %)

Experimental campaign Spring 2004 – Summer 2006

- *Search for excited states in neutron rich Mg, Si and S* ($^{36}S + ^{208}Pb$)

X.Liang, Paisley; F.Azaiez, Orsay

- *Nuclear spectroscopy of neutron rich nuclei in the N=50 region* ($^{82}Se + ^{238}U$)

G.Duchêne, Strasbourg; G.de Angelis, Legnaro (poster by G.Duchêne)

- *Pair transfer effects in $^{90}Zr+^{208}Pb$* ($^{90}Zr + ^{208}Pb$)

L.Corradi, Legnaro

- *Identification of the 6^+ state in ^{54}Co* ($^{54}Fe + ^{54}Fe$)

A.Gadea, Legnaro

- *Resonances in $^{24}Mg+^{24}Mg$ and molecular states in ^{48}Cr* ($^{24}Mg + ^{24}Mg$)

F.Haas, Strasbourg

- *Excited states in ^{31}S* ($^{32}S + ^{58}Ni$)

D.R.Napoli, M.Mărginean, Legnaro

- *Decay properties of pairing vibration states populated in transfer reactions* ($^{40}Ca + ^{96}Zr$)

S.Szilner, Zagreb

- *Large angle scattering of $^{40}Ca + ^{X}Zr$.* ($^{40}Ca + ^{xx}Zr$)

G.Montagnoli, Padova

- *Shell-model states around doubly-magic ^{48}Ca* ($^{48}Ca + ^{238}U$)

R.Broda, Krakow

- *Test of the Differential Plunger Technique* ($^{64}Ni + ^{208}Pb$)

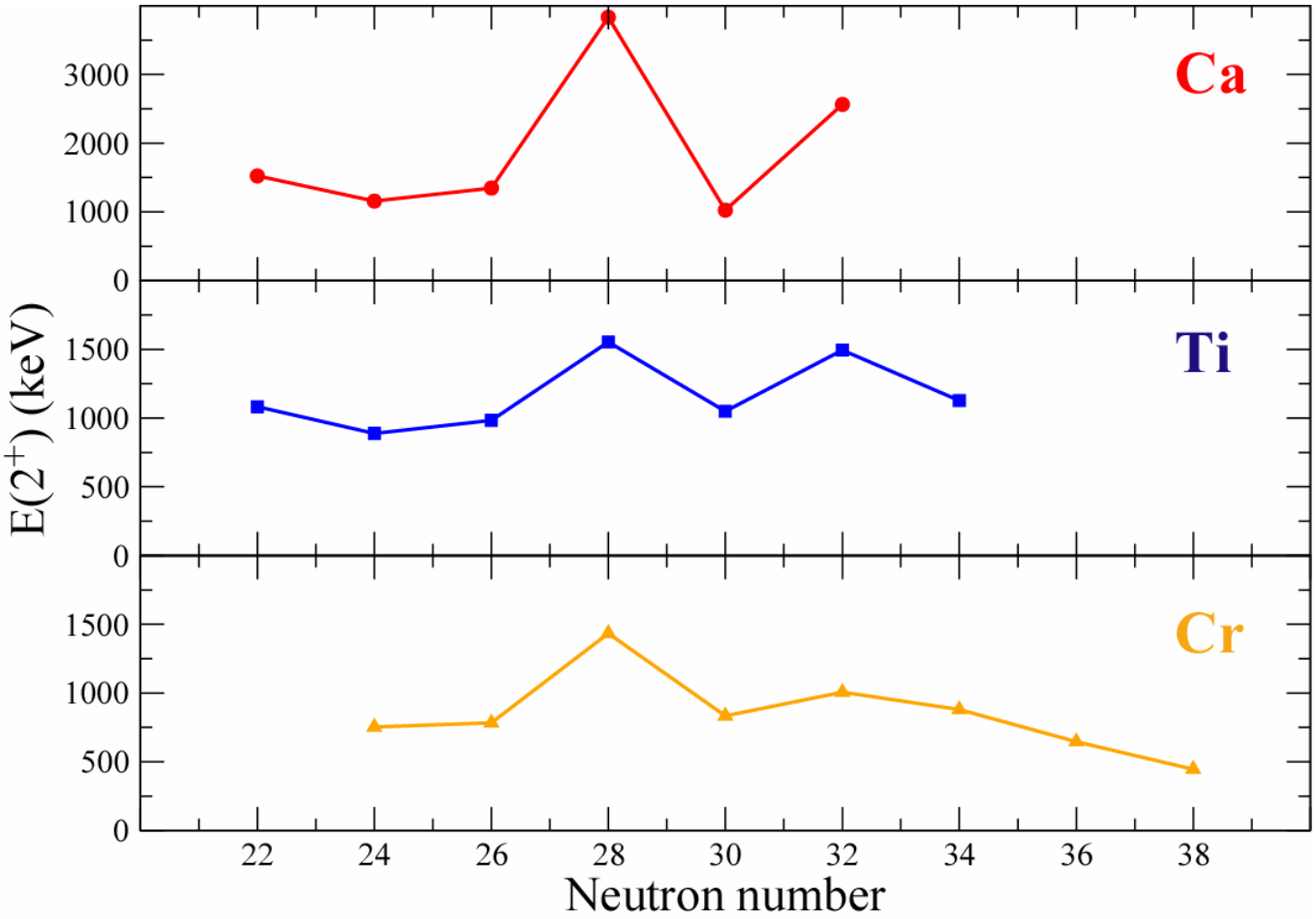
N.Mărginean, Legnaro; A.Dewald, Köln

- *Spectroscopy of deformed neutron rich A ~ 60 nuclei* ($^{64}Ni + ^{238}U$)

S.M.Lenzi, Padova; S.J.Freeman, Manchester (this talk)

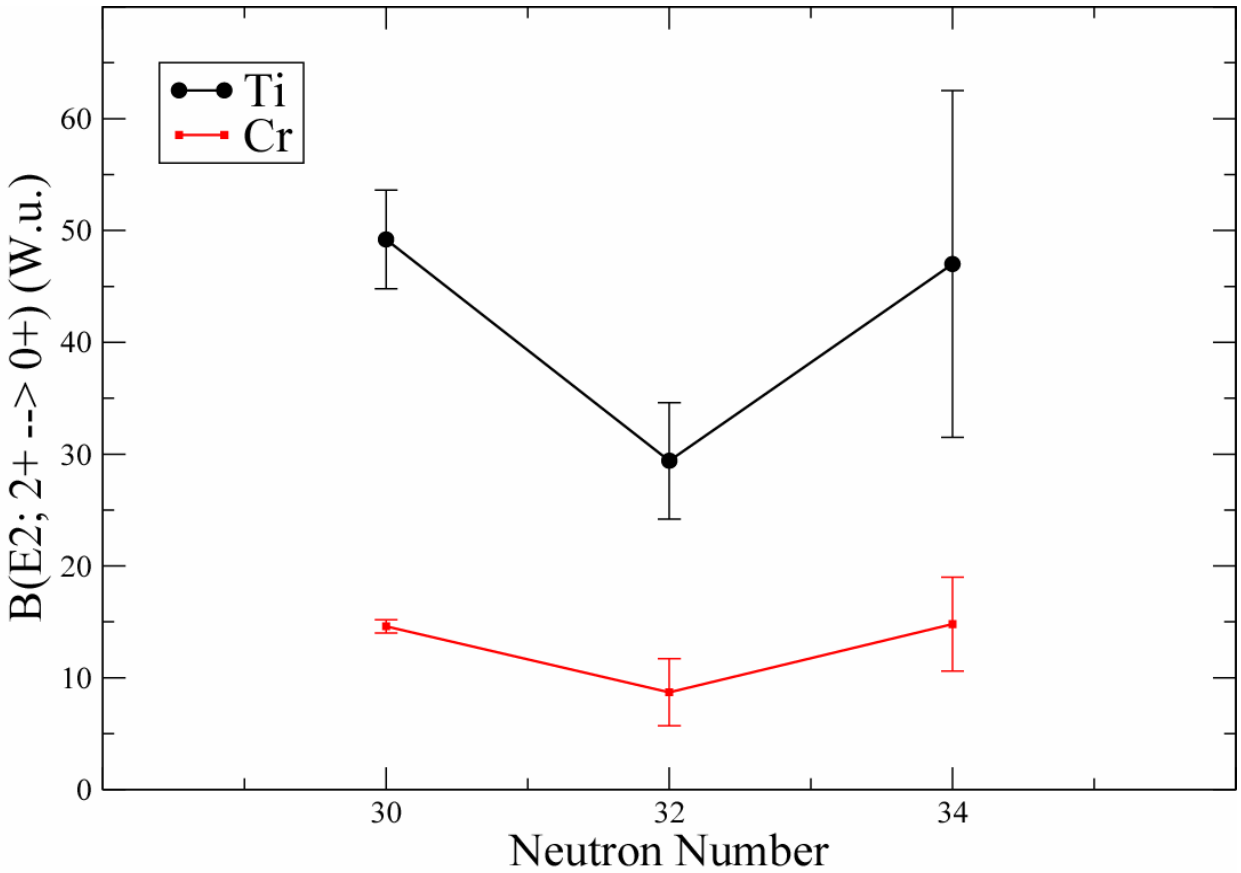
Shell closures and collectivity in n-Rich A≈50-60 Nuclei

Systematics of the 2^+ energy in the Ca and Ti even-even isotopes suggests that *N=32* might be a good (sub)shell closure. The same systematics for the Cr isotopes points to quite a collective behaviour for the heavier isotopes.



Shell closures and collectivity in n-Rich A≈50-60 Nuclei

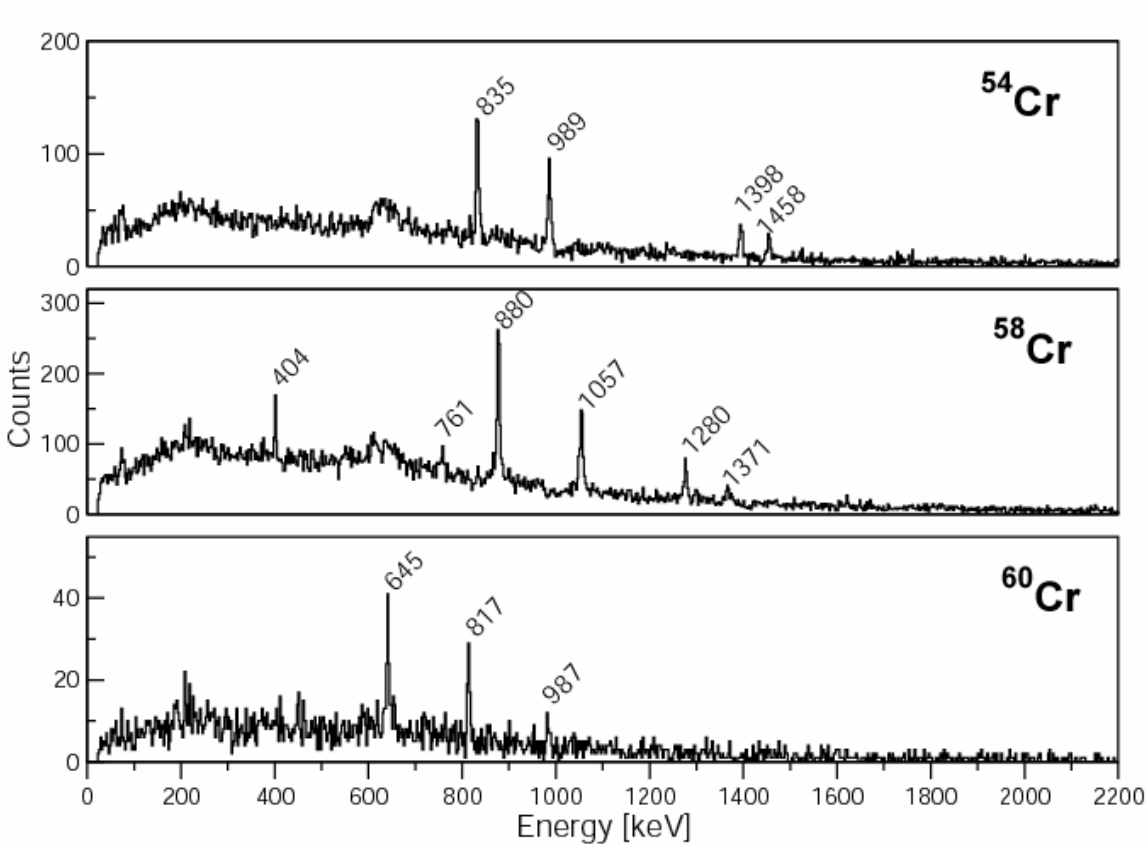
Recent transition probability data from RISING and MSU are consistent with a sub-shell closure at N=32. The spectroscopic information for the heavy Cr isotopes, prior to this measurement, was mostly limited to the energy of the first 2^+ state, identified from β-decay experiments.

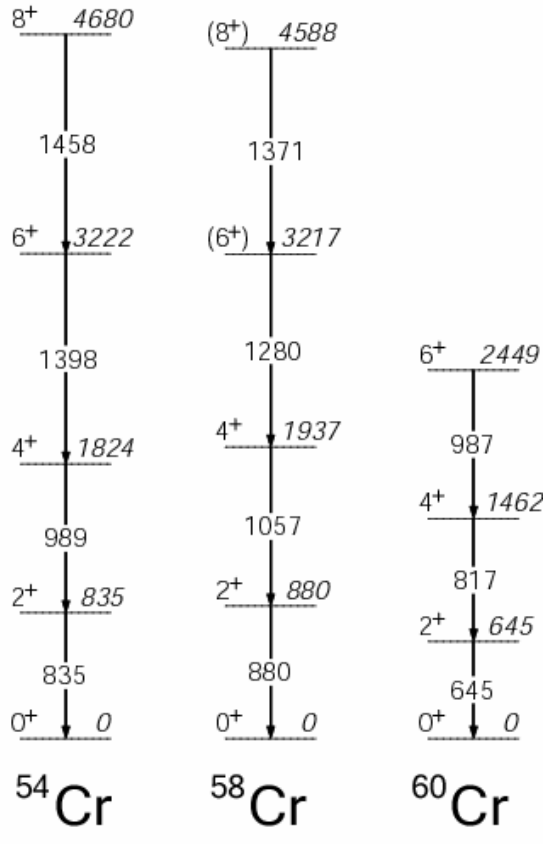


A.Bürger et al,
*PLB **622**, 29 (2005)*
D.-C.Dinca et al,
*PRC **71**, 041302(R) (2005)*
J.I.Prisciandaro et al,
*PLB **510**, 17 (2001)*
O.Sorlin et al,
*EPJA **16**, 55 (2003)*

Spectroscopy of heavy Cr isotopes

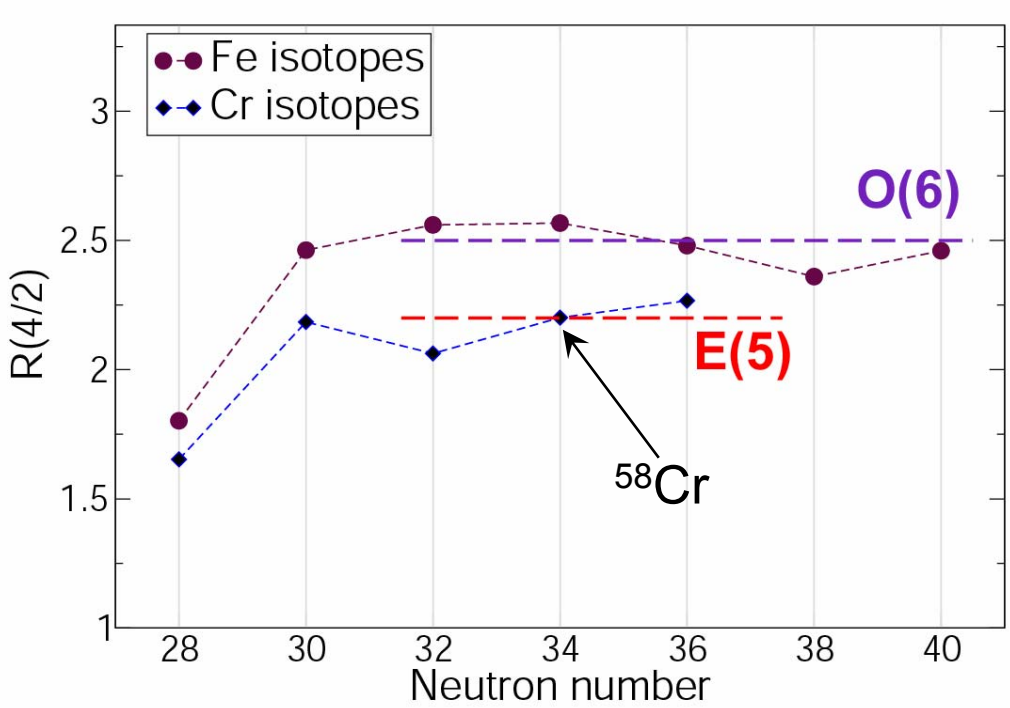
^{64}Ni(404 MeV) + ^{238}U

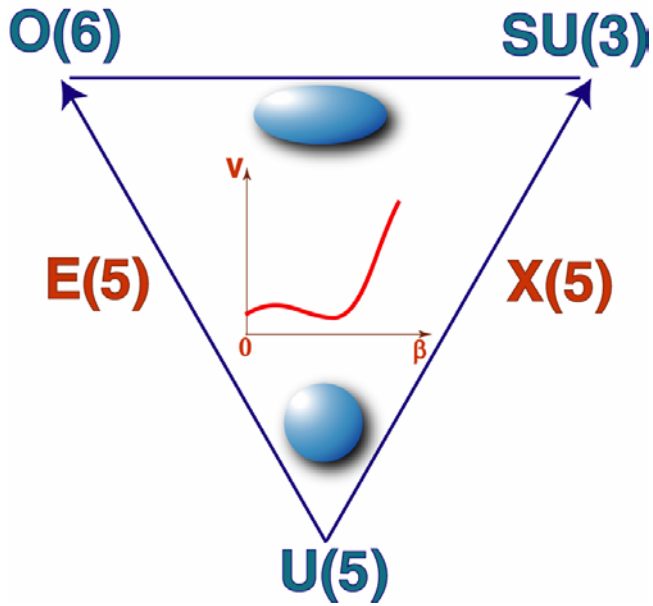




γ rays from the yrast levels of ^{58}Cr observed for the first time

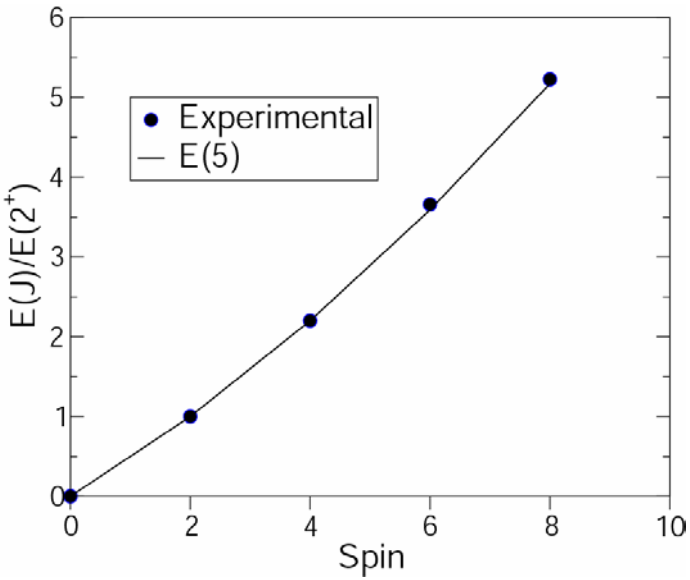
γ-softness in heavy Cr and Fe isotopes





- The R(4/2) ratio for the heavy Fe isotopes is very close to the 2.50 value characteristic of γ-soft rotors
- The value for the heavier Cr isotopes is also close to the same limit
- ^{58}Cr lies exactly at the 2.20 value predicted for the E(5) dynamical symmetry

A candidate for a critical point



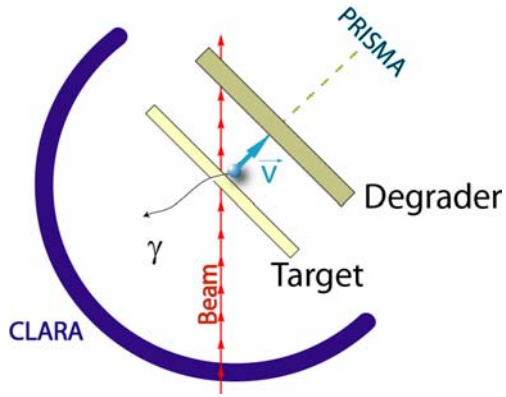
	EXP.	E(5)	IBA	KB3G	FPD6	GXPF1
8^+	4598	4550	4442	4447	4743	4946
6^+	3219	3159	3130	2990	3188	3299
4^+	1937	1936	1937	1770	1885	2051
2^+	880	880	882	880	870	1102
0^+	0	0	0	0	0	0

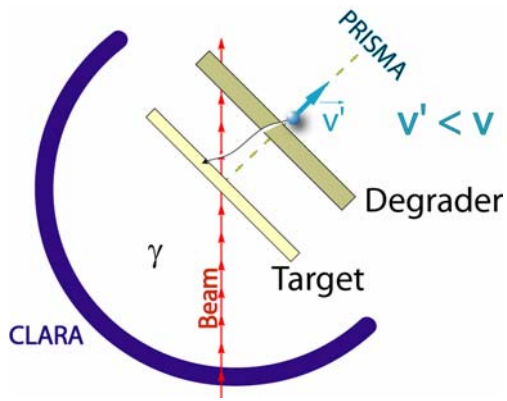
- The predictions of the E(5) symmetry are in good agreement with the experimental values for the yrast band, as well as with the results of several Large-Scale Shell-Model calculations
- Transition probabilities are needed to decide whether ^{58}Cr lies at the E(5) critical point

*N. Mărginean et al., PLB **633** (2006) 696*

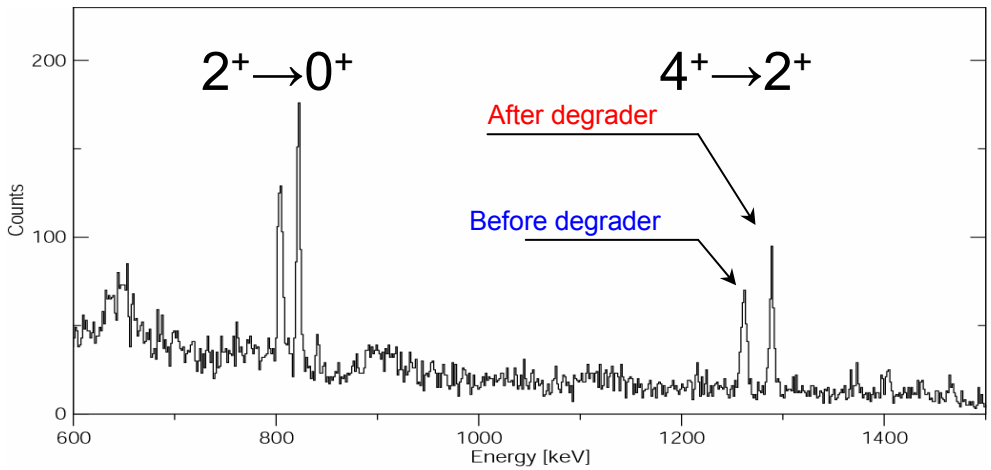
Differential plunger with CLARA/PRISMA

The differential plunger technique, implemented in collaboration with IKP Köln, relies, similarly to the RDDS method, on the measurement of the fraction of photons emitted before and after a degrader foil (thin enough to let the recoils reach the spectrometer)





^{60}Fe – simulation based on existing experimental data



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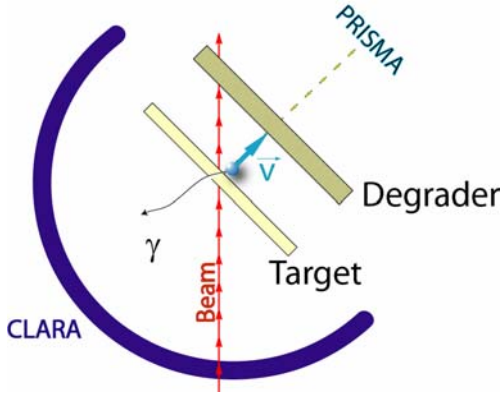
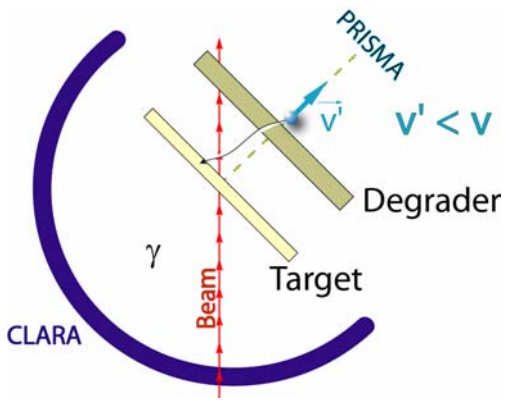
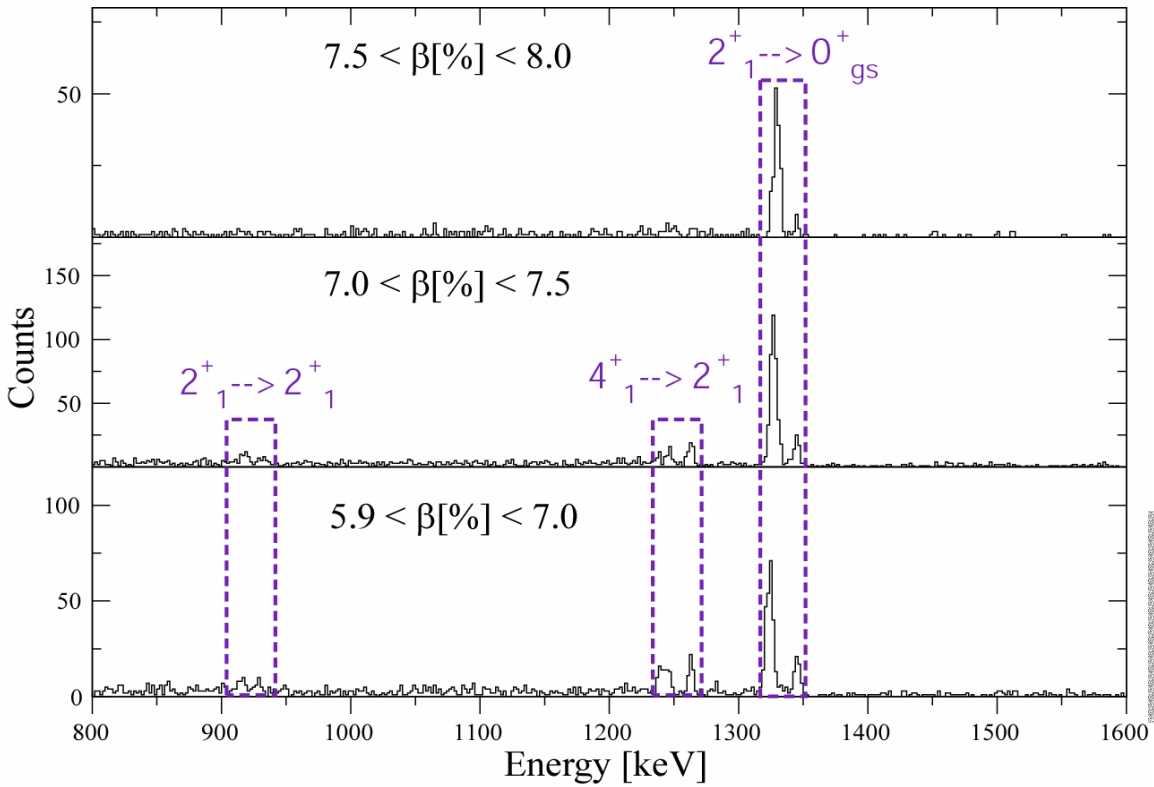


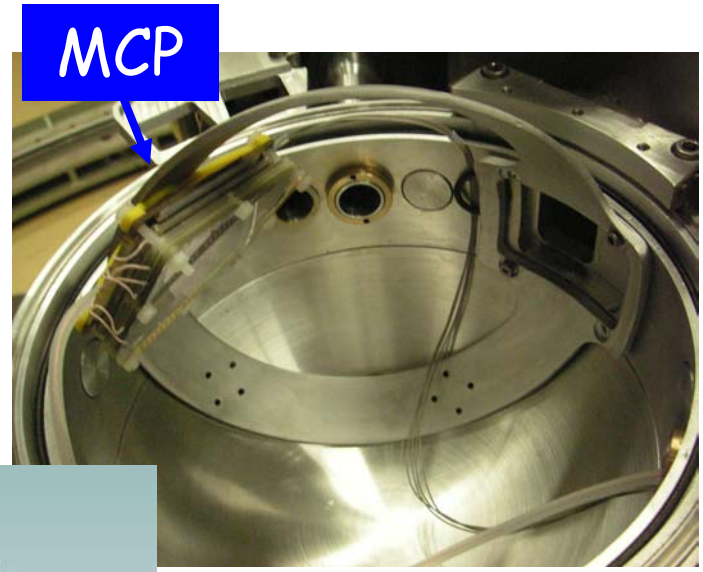




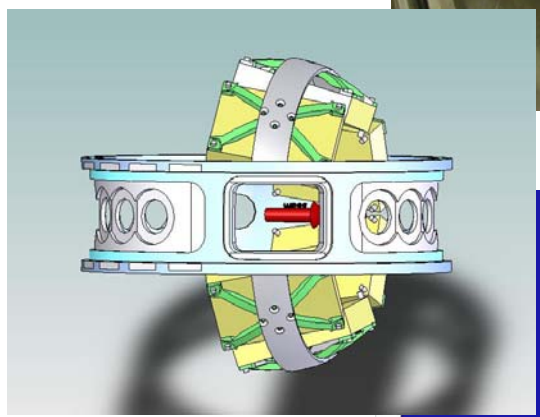
Ni transitions.

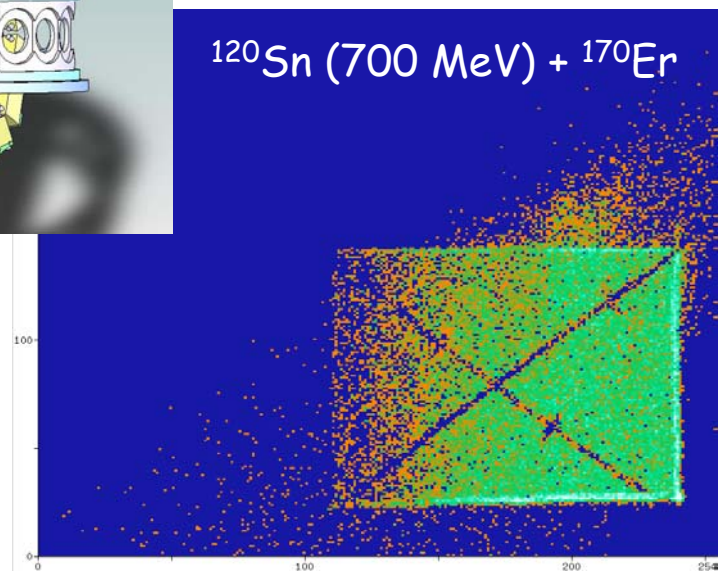
Other developments: the DANTE MCP Array

DANTE is a highly efficient array of position-sensitive MCP detectors, developed in collaboration with FLNR Dubna and recently commissioned and used in two in-beam experiments.



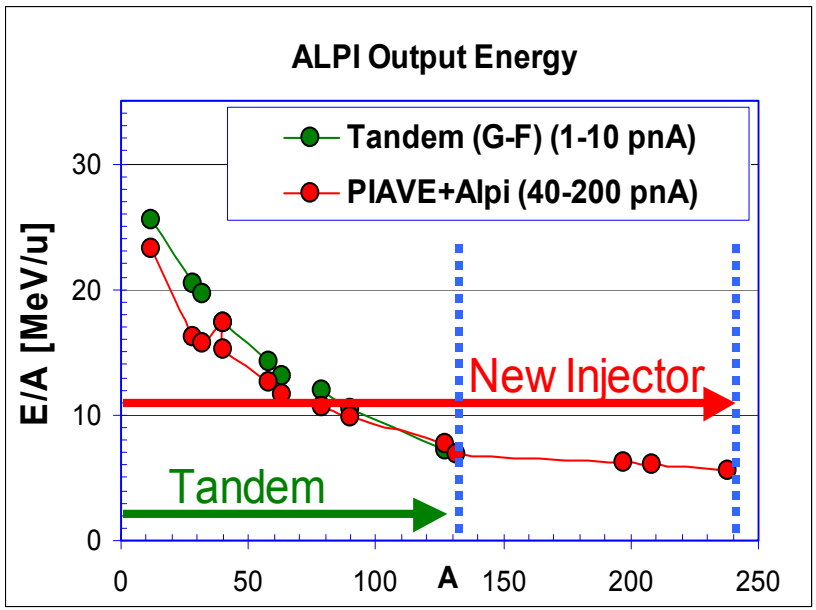
Using $\gamma\gamma$-DANTE coincidences it will be possible to build level schemes for nuclei identified for the first time with PRISMA (two experiments at the price of one!)



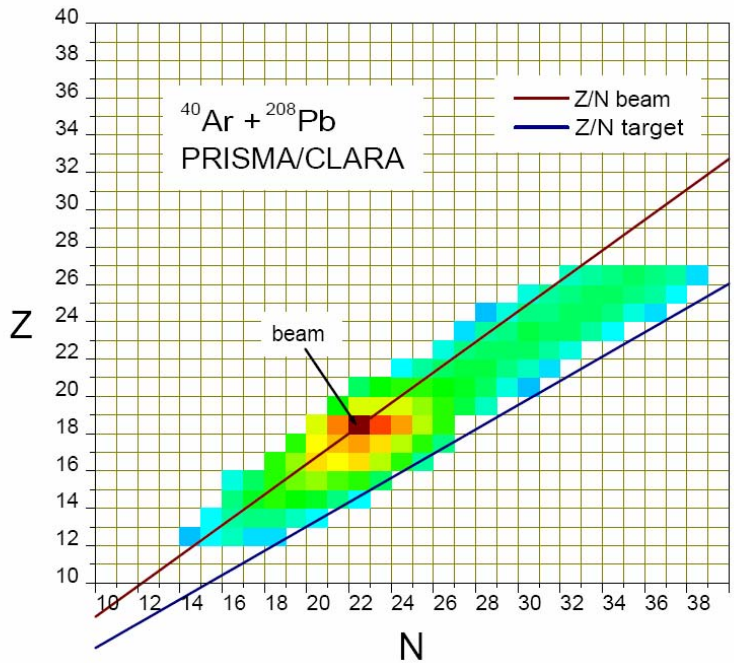


The PIAVE/ALPI accelerator

The PIAVE/ALPI accelerator is currently entering routine operation at LNL, providing higher beam intensities, heavier beams and beams otherwise not available with the TANDEM/ALPI accelerator, which will be very useful for the current and future experimental program. ^{22}Ne and ^{40}Ar test beams were already successfully delivered to the PRISMA/CLARA facility.

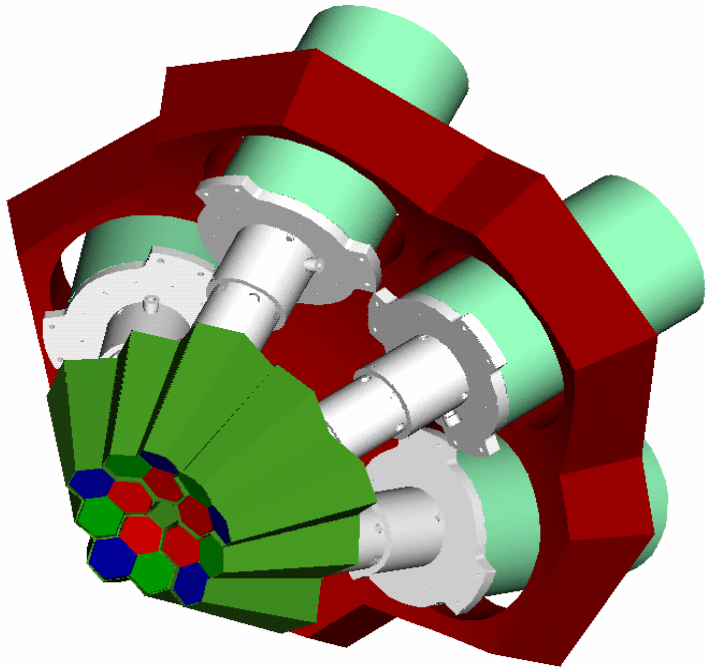


^{40}Ar test beam, January 2006



The near future: AGATA at PRISMA

According to the present plans, CLARA will be dismounted in the second half of 2007 and it will be replaced by the AGATA Demonstrator Array of 15 highly segmented germanium detectors (36-fold segmentation), providing higher efficiency and better energy resolution



→ Exciting perspectives for the campaign of measurements foreseen in 2008!

See talk by J.Gerl

Summary

- Valuable information on moderately n-rich nuclei has been collected using multinucleon transfer and deep inelastic collisions with stable beams at the CLARA/PRISMA setup
- It will be possible to use the same techniques developed for stable beams with the future RIB facilities
- In the near future, we expect interesting results from the AGATA demonstrator coupled to PRISMA, thanks also to the heavier beams provided by PIAVE.

Many thanks to the CLARA/PRISMA Collaboration!

- **Italy**
  - INFN LNL-Legnaro
  - INFN and University Padova
  - INFN and University Milano
  - INFN and University Genova
  - INFN and University Torino
  - INFN and University Napoli
  - INFN and University Firenze
  - University of Camerino
- **Spain**
  - University of Salamanca
- **Romania**
  - NIPNE Bucharest
- **France**
  - IReS Strasbourg
  - GANIL Caen
- **U.K.**
  - University of Manchester
  - Daresbury Laboratory
  - University of Surrey
  - University of Paisley
- **Germany**
  - HMI Berlin
  - GSI Darmstadt